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ABSTRACT

There was no evident relationship between the operation of the Hanford reactors and the numbers of fish spawning in the Hanford reach of the river. Recent increases in numbers of fall chinook spawners seemed more closely associated with the construction of dams downstream and immediately upstream from Hanford, and the probably displacement of fish from these areas. Water temperatures were less than 15° C during the peak of spawning, well within the upper tolerance limits for this species.

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INTRODUCTION

The effects of the Hanford atomic reactor effluents on the Columbia River biota have been studied since 1945, shortly after the start of reactor operation in 1944. These studies have dealt with the radiation effects, which received particular emphasis during the early years because of the paucity of information on aquatic radiobiology; the chemical effects, especially that of dichromate, an additive to the reactor cooling water; and thermal effects, which have received more attention in later years due to the recent concern with the effects of heat on water quality and natural environments. The effects of heated discharges on anadromous fish, with particular reference to Hanford has been reported by Nakatani (1).

It was recognized early that the reactor effluents may be potentially harmful to the Columbia River fish. Special attention has been directed at the chinook almon (Oncorhynchus tshawytscha), because of its economic importance, its relatively high sensitivity to pollution and its use of the Hanford reach for spawning. The population of fall chinooks spawning near Hanford has greater exposure to reactor effluents than other anadromous fishes in the Columbia River. The adults may be resident in the Hanford reach for up to three months, and the early life stages, from egg to juvenile migrant are in the area from five to seven months. Observations on the local salmon stock were begun in 1946 by means of aerial survey of their spawning grounds. The objective of the first year's survey was to locate the spawning areas. In subsequent years attempts were made to estimate population size through the use of the numbers of redds (nests) counted as a population index. This report summarizes the results of surveys made of the locally spawning fall chinook from 1947 to 1969.

METHODS

Estimates of the locally spawning population were made each fall in the section of river between Richland and Priest Rapids (Figure 1). From one to seven surveys were made each year with a light fixed-wing aircraft flying at 800 to 1200 feet (244 to 366 m) altitude, and at air speeds of 75 to 100 miles (120 to 161 km) per hour. When salmon redds were widely spaced, they were enumerated individually; but when they were close together or overlapping, they were counted in units of ten. On each survey two or more counts were made of areas of heavy spawning. The angle of approach of the airplane to the area of interest was varied to obtain optimum visibility. Water depth and turbidity, wind action on the water and light reflection from the water surface, and stability of the aircraft were some of the variables that limit direct comparison of survey results. The freshly excavated redds appear from the air as light colored, regularly shaped circular or oval areas that stand out in contrast to the normally darker algae covered river bottom. They remain visible for approximately six weeks before their surface is recolonized by algae growth. As pointed out by Bevan (2) aerial

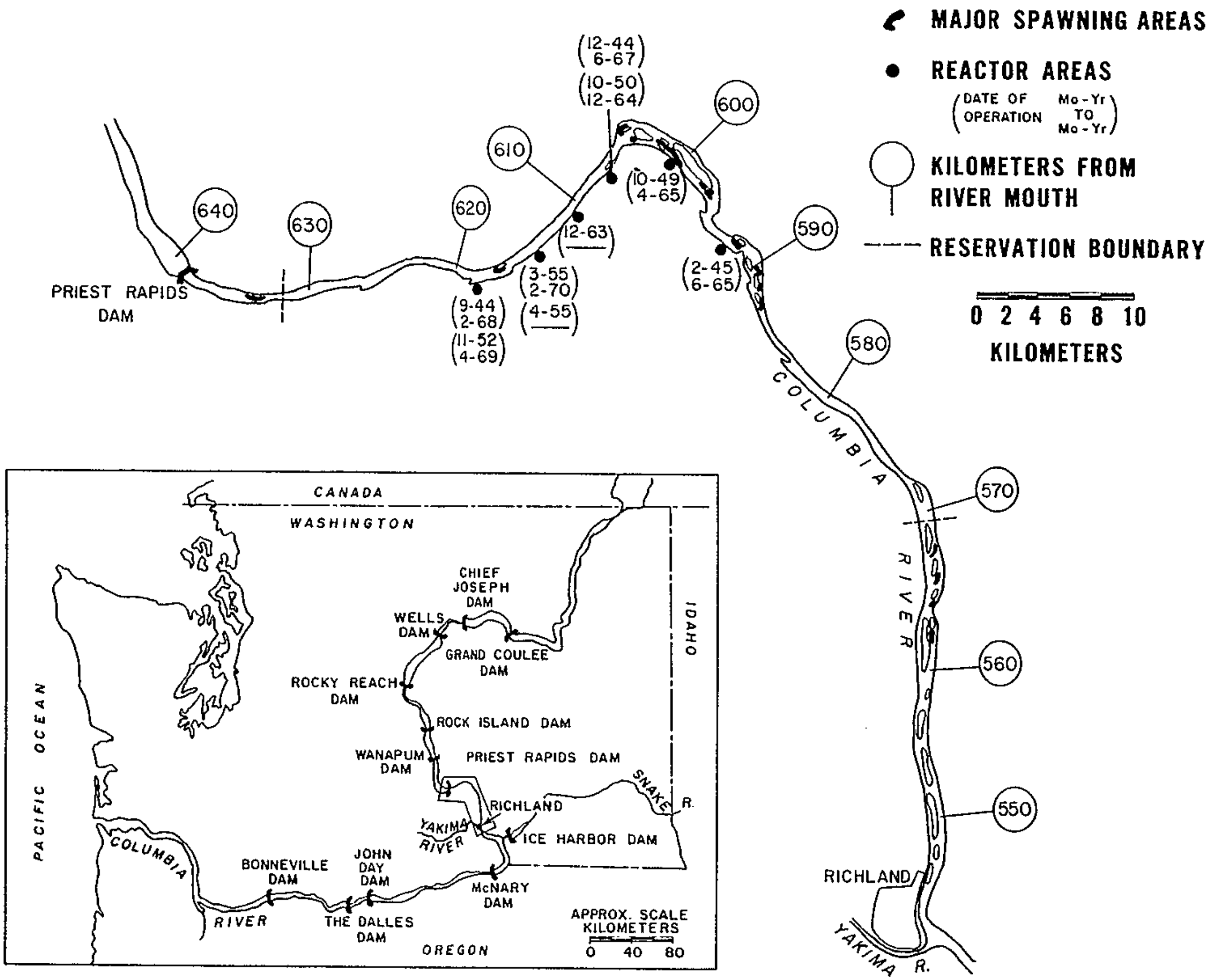

FIGURE 1. HANFORD CHINOOK SALMON SPAWNING AREA

surveys are most useful in obtaining a relative index for determining general year-to-year changes in population density, but are of limited value for determining total numbers in any one year.

Spawning generally extended from about the middle of October to the second or third week in November. However, Hanson (4) reported two pulses of spawning activity in 1958. The first occurred about two weeks earlier than usual, with the start of spawning in the last part of September. Early spawning was also noted in other areas in the Columbia River system (op cit.) in 1958. Chambers et al. (cited by Smith 5) reported early spawning fall chinook in the artificial channel at McNary Dam in 1958.

Counts were made by the author in all but four of the twenty-three years of observation, thereby reducing individual differences. Counts were made by R. F. Foster in 1947 and 1948, and by W. C. Hanson in 1957 and 1958.

The total redd count for any one season is defined as the sum of the maximum number of redds observed in each of the several spawning areas regardless of the particular survey on which the highest number was observed. This approach was judged to be preferrable to taking the greatest number obtained on one of several surveys of the Hanford reach because changing conditions, particularly water depth and weather, often occurred during the course of a single flight. A factor of seven was used to convert numbers of redds to numbers of fish. This factor was calculated from the difference in fall chinook passage over McNary and Ice Harbor-Priest Rapids Dams, and an estimated 25 percent "unaccounted for" fraction of the run in this part of the river. It is in reasonable agreement with the factor of 8.5 developed by Meekin (3) for main stem

Columbia River spawning above Rocky Reach Dam in 1966.

Several unsuccessful attempts were made to use photography as an aid for estimating the numbers of salmon redds. Water depth and turbidity were limiting. Much of the local spawning took place at depths greater than five meters. Meekin (6) has reported chinook spawning at a depth of ten meters in the middle Columbia River. Techniques for measuring differences in color density on the river bottom are being developed by Battelle and may offer some improvement in future aerial survey work.

RESULTS AND DISCUSSION

Reactor Operation

The primary objective of this study was the examination of the effect of reactor operation on the local salmon population. Radioactive isotopes, chemicals and heat are introduced into the river in the reactor effluents. The amounts and rates of effluent discharge and effluent temperatures are not available in an unclassified form because of their direct relationship to reactor production rates.

The number of operating reactors, which has varied widely over the twenty-three years of salmon survey, is used as a rough index of the amount of effluent discharged to the river. This does not imply a direct linear relationship between number of reactors and effluent discharge but only indicates a general direct relationship. Figure 1 shows the reactor locations, dates of operation, and geographical relationship to the principal spawning areas in the Hanford area. From 1944 to 1955, two to six reactors were operating; 1955 to 1964, eight reactors; nine, the maximum, in 1964; and a reduction to only three in 1969. Another reactor was closed in early 1970, leaving only two remaining, one of which releases heat but not chemical or radioactive materials. The major spawning areas between kilometer 585 to 605 are downstream from the effluent outfalls and have been subjected to incompletely mixed effluents. In several years salmon spawning was observed within 100 meters downstream from an effluent outfall. The reactor effluents are discharged at the river bottom near mid-channel and are quite rapidly mixed with the river water. Because of their warmer temperature they tend to rise to the river surface near the point of discharge, thereby reducing their influence on the river bottom near the point of discharge.

The relationship between the number of operating reactors and the redd counts are shown in Figure 2. The marked rise in numbers of spawning salmon during 1965 to 1969 is not considered to be related to the decrease in reactor operation during that period, but due to other factors, such as displacement from other main stem spawning areas, which will be discussed later. If one assumes that there have been no outside influences on the size of the local spawning stock, such as recruitment from other main stem spawning areas, the rise in the adult population in 1965 to 1969 must be a reflection of the success of spawning in 1961 to 1965, a period of near maximum reactor operation. A more realistic comparison between reactor operation and the local salmon population could perhaps be obtained by shifting the curve, showing the number of redds in Figure 2, back three or four years.

The areas selected for spawning in the section of the river receiving reactor effluents have varied little over the years of observation, and

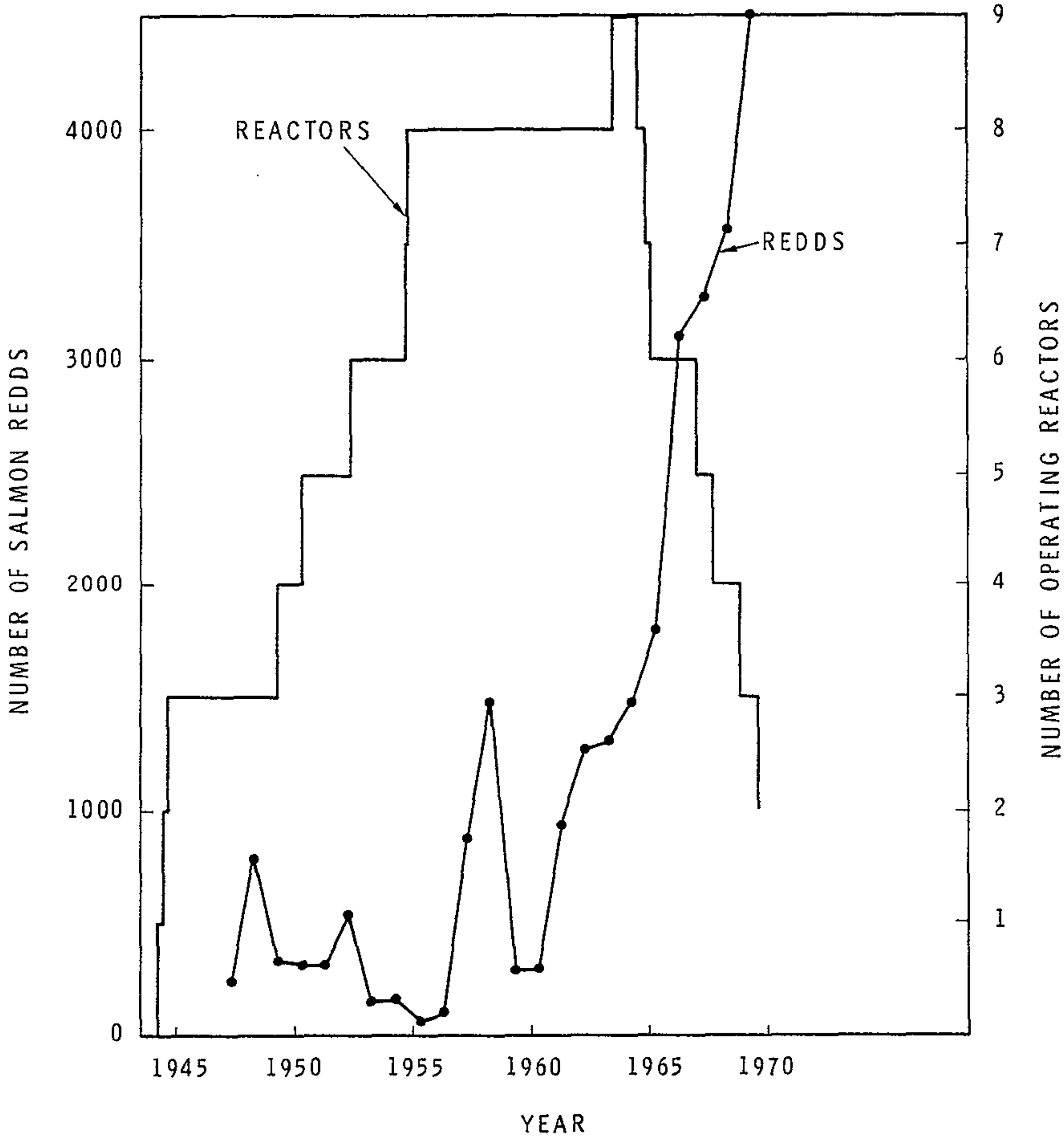

FIGURE 2. SALMON SPAWNING AND REACTOR OPERATION

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have appeared to be independent of reactor operation. The yearly redd counts for the major spawning areas are given in Table 1, and are expressed as percentage of the total annual counts between Richland and Priest Rapids in Figure 3. Greater stability in the percentage utilization of the major spawning areas, particularly at km 600-605 and km 633, is apparent since 1959. Use of these areas may be approaching their carrying capacities.

Effect of River Dams

It is an established fact that Columbia River dams affect both the up and downstream migration of anadromous fishes. These dams are listed in Table 2.

In the Hanford area the yearly number of redds has fluctuated widely, from a minimum of 64 in 1955 to about 4500 in 1969 (Table 1). Priest Rapids Dam, completed in 1959, appears to have influenced the distribution and size of the Hanford spawning population. Before 1959 an average of 17 percent of the redds were found in the first suitable spawning area downstream (km 633) from the dam site, but upstream from the reactor outfalls. Since the completion of the dam about 41 percent of the spawning has taken place in this area. From 1966 to 1969 the spawning area below Priest Rapids Dam has been very heavily seeded, with nearly complete overlapping of the redds. It is possible that the dam presents a partial barrier to the upstream movement of adult fall chinook, and has resulted in increased spawning in the first suitable area downstream. Schoning and Johnson have reported the delay of upstream movement of salmon by a river dam (7). A 6.3 percent fallback of spring chinook with only a 50 percent reascent has been reported by Johnson at Ice Harbor Dam (8). The number

TABLE 1. HANFORD FALL CHINOOK SPAWNING 1947-69

YEAR	NUMBER OF REDDS							
	560-570 KM* RINGOLD	588-592 KM	596 KM WHITE BLUFFS	600-605 KM	618 KM COYOTE RAPIDS	633 KM MIDWAY	OTHER	TOTAL
1947	0	15	25	10	0	75	115	240
1948	120	330	38	219	0	25	53	785
1949	45	50	6	195	0	1	33	330
1950	24	43	38	151	3	46	11	316
1951	5	10	45	151	5	95	3	314
1952	73	101	40	221	3	78	23	539
1953	7	5	16	38	0	83	0	149
1954	4	5	8	127	0	6	7	157
1955	0	12	0	47	0	4	1	64
1956	0	3	7	59	0	17	6	92
1957	27	173	55	440	43	132	2	872
1958	49	249	133	520	192	258	83	1485
1959	1	0	36	101	32	111	0	281
1960	0	31	22	99	38	105	0	295
1961	0	27	43	201	23	640	4	939
1962	6	195	66	456	1	535	2	1261
1963	0	283	127	506	14	370	3	1303
1964	5	163	111	510	37	624	27	1477
1965	4	262	211	588	54	659	11	1789
1966	10	279	267	1206	37	1300	2	3101
1967	28	388	273	1192	17	1340	29	3267
1968	117	595	188	1069	52	1520	39	3560
1969	265	820	427	1446	50	1500	0	4508

*KILOMETERS FROM RIVER MOUTH

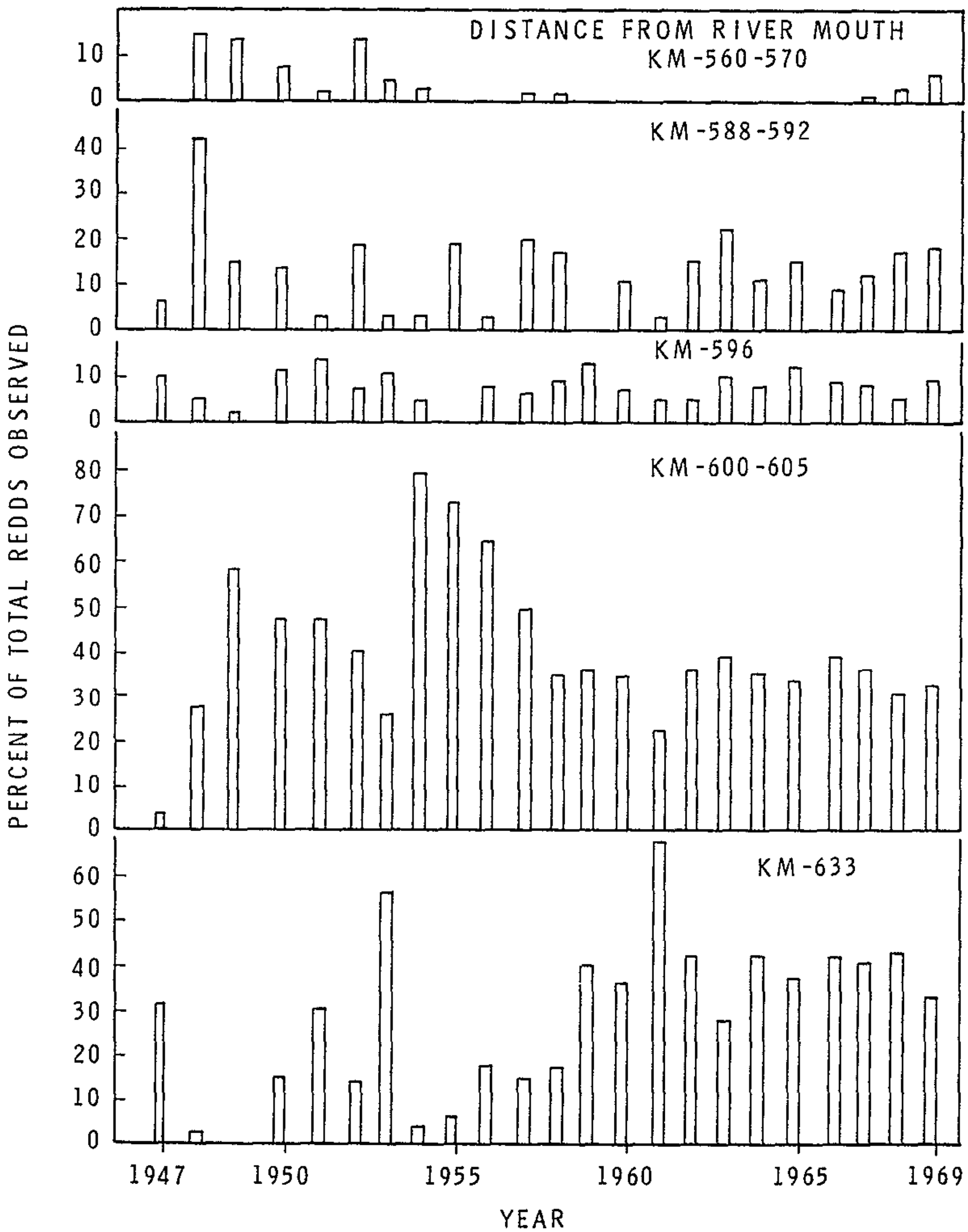

FIGURE 3. RELATIVE UTILIZATION OF MAJOR CHINOOK SALMON SPAWNING AREAS

TABLE 2. COMPLETION DATES OF COLUMBIA AND SNAKE RIVER DAMS WHICH AFFECTED ANADROMOUS FISH (TAKEN FROM: "THE 1969 STATUS REPORT OF THE COLUMBIA RIVER FISHERIES", FISH COMM. ORE. AND STATE OF WASH. DEPT. FISH., JAN. 1970)

NAME OF DAM	YEAR INITIAL SERVICE	GROSS HEAD METERS (FEET)	LENGTH OF RESERVOIR KILOMETERS (MILES)
COLUMBIA RIVER			
BONNEVILLE	1938	18 (59)	72.4 (45)
THE DALLES	1957	26.2 (86)	49.9 (31)
JOHN DAY	1968	32 (105)	122.3 (76)
McNARY	1953	26.2 (86)	98.1 (61)
PRIEST RAPIDS	1959	25.6 (84)	29 (18)
WANAPUM	1963	24.2 (80)	61.1 (38)
ROCK ISLAND	1933	12.2 (40)[1]	33.8 (21)
ROCKY REACH	1961	28.3 (93)	67.6 (42)
WELLS	1967	21.9 (72)	48.3 (30)
CHIEF JOSEPH	1955	53.3 (175)	82.1 (51)
GRAND COULEE	1941	104.5 (343)	243 (151)
SNAKE RIVER			
ICE HARBOR	1961	29.6 (97)	51.5 (32)

[1] 15.5M (51 FT) HEAD BEFORE COMPLETION OF WANAPUM DAM

of fallbacks may vary with dam and river flow but probably occurs to some degree at all dams. Those fish that do not reascend Priest Rapids Dam may spawn in the area downstream.

The increase in the utilization of the spawning area immediately downstream from Priest Rapids Dam does not seem to have occurred at the expense of the areas below the reactors (Figure 4). There has been an appreciable increase in the numbers of spawners below the reactor areas, particularly since 1962. In addition to the contribution from possible fall-back of fish from Priest Rapids to the Hanford reach, the destruction of main stem spawning areas by dams downstream has probably also contributed to the larger numbers of spawners in recent years (See Fig. 1 for dam location and Table 2 for date of completion).

Coincident with the establishment of The Dalles Dam in 1957 there was a sharp increase in the fall chinook run over McNary Dam (Table 3). Davidson (9) reported an increase in escapement above The Dalles due to the elimination of the Indian fishery at Celilo Falls, which was flooded by The Dalles Dam. Mathews and Paulik (10) have suggested that the increase at McNary in 1957 and thereafter was the result of upstream displacement of spawners from the section of the Columbia River flooded by The Dalles Dam, and the more stringent regulations on the fall run commercial gill net fishery in the Columbia River. They also reported a similar substantial increase in the fall chinook passing Rock Island Dam in 1957, and a greater increase in 1960 to 1962, after the completion of Priest Rapids Dam but before the completion of Wanapum Dam in 1963. Most of the main stem spawning between Priest Rapids and Rock Island Dam before the establishment of Priest Rapids Dam was in the section of river upstream from the Wanapum Dam

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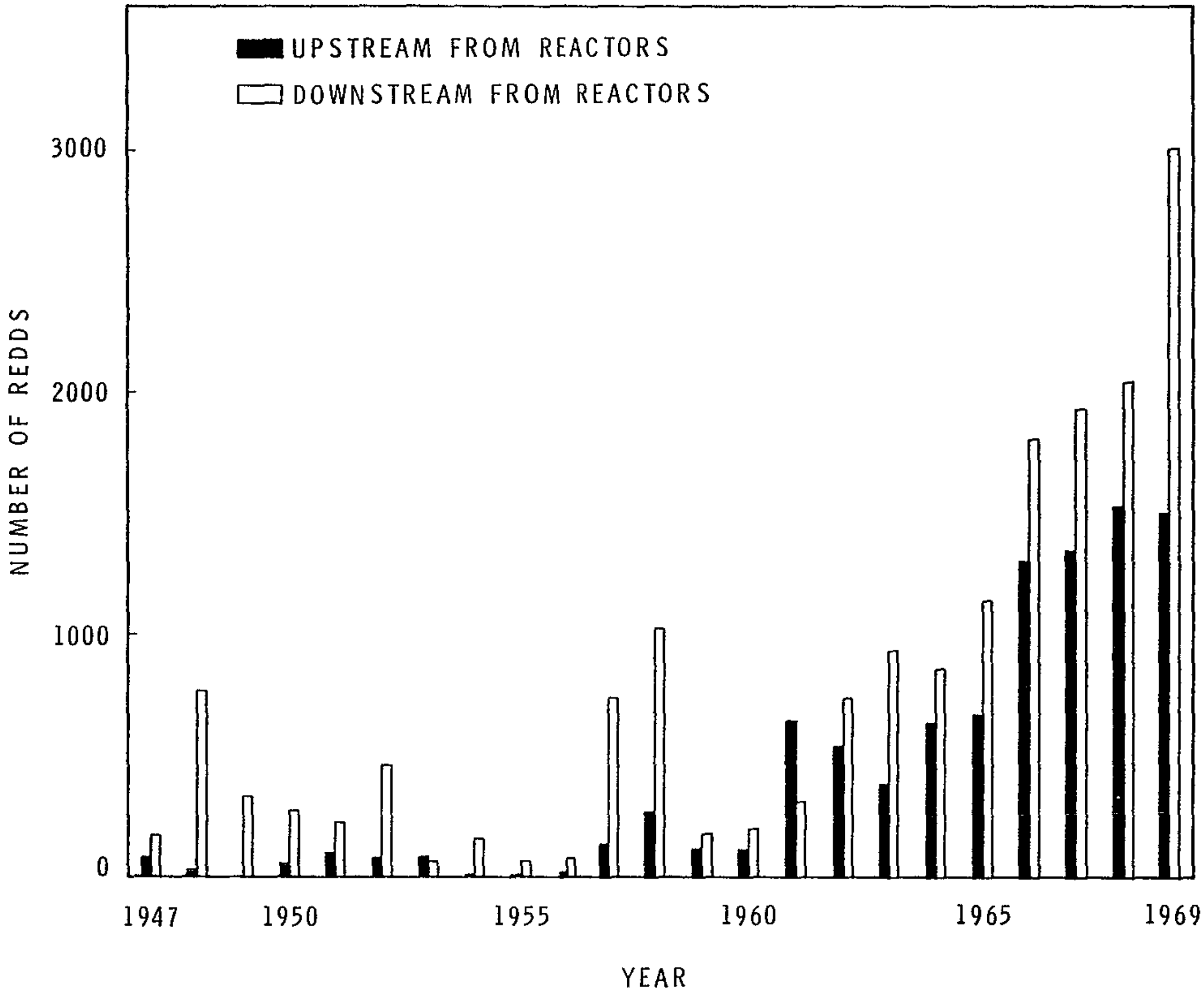

FIGURE 4. SALMON SPAWNING ABOVE AND BELOW REACTORS

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TABLE 3. RELATIONSHIP OF FALL CHINOOK PASSAGE BETWEEN COLUMBIA RIVER DAMS AND MAIN STREAM SPAWNING FROM McNARY DAM TO ROCK ISLAND DAM

YEAR	A BONNEVILLE[1] COUNT (AUG.1-DEC.31)	B ESCAPEMENT[2] ABOVE BONNEVILLE[1]	C THE DALLES[1] COUNT (AUG 4 DEC 31)	D JOHN DAY[1] COUNT (AUG 6 NOV 9)	E McNARY[1] COUNT (AUG 9 OCT 31)	F ICE HARBOR[1] COUNT (AUG 12 OCT 31)	G HANFORD[4] COUNT	H PRIEST RAPIDS[3] COUNT (AUG 18 OCT 31)	I PRIEST RAPIDS[4] TO ROCK ISLAND COUNT	RATIO (C/B)X100	RATIO (D/B)X100	RATIO (E/B)X100	RATIO (F/B)X100	RATIO (G/B)X100	RATIO (H/B)X100	RATIO (I/B)X100	RATIO (F/E)X100	RATIO (G/E)X100	RATIO (H/E)X100	RATIO (I/E)X100
1947	307,955	114,353					3,640		2667					3.2		2.3				
1948	318,590	108,142					5,495		4634					5.1		4.3				
1949	180,891	81,537					2,310		1757					2.8		2.2				
1950	250,482	190,505					2,212		3262					1.2		1.7				
1951	137,617	39,336					2,198		5138					5.6		13.1				
1952	220,396	103,044					3,773		3693					3.7		3.6				
1953	104,328	33,307					1,043		1274					3.1		3.8				
1954	106,784	38,579			13,476		1,099		1225			34.9		2.8		3.2		8.2		9.1
1955	105,318	55,028			16,426		448		777			29.9		0.81		1.4		2.7		4.7
1956	134,268	72,227			11,290		644		1176			15.6		0.89		1.6		5.7		10.4
1957	131,815	93,009	86,294		70,607		4,306		5292	92.8		75.9		4.6		5.7		6.1		7.5
1958	249,314	167,405	160,074		97,528		10,395		4151	95.6		58.3		6.2		2.5		10.7		4.3
1959	194,943	139,886	85,225		55,230		1,967		98	60.9		39.8		1.4		0.78		3.5		0.18
1960	101,282	72,055	63,241		47,337		2,065	12,195	819	87.8		65.7		2.9	16.9	1.3		4.4	25.8	1.7
1961	116,824	90,022	71,328		41,200		6,573	14,286	2905	79.2		45.8		7.3	15.9	4.1		16.0	34.7	7.1
1962	118,024	89,260	60,986		44,116	30,849	8,827	15,024	6279	68.3		49.4	34.7	9.9	16.8	10.3	68.1	20.0	29.5	14.2
1963	139,075	90,717	60,699		57,365	13,537	9,128	18,606	0	66.9		63.2	14.9	10.0	20.7	0	23.6	15.9	32.8	0
1964	172,463	119,848	66,798		58,593	11,097	10,339	18,416	1554	55.7		48.9	9.3	8.6	15.0	2.3	18.9	17.6	30.8	2.7
1965	157,494	115,407	100,965		76,326	12,354	12,529	21,508	350	87.4		66.1	10.7	10.9	20.4	0.35	16.2	16.4	30.8	0.46
1966	155,445	112,286	82,981		75,119	15,018	21,707	19,221	686	73.9		66.9	13.4	19.3	17.1	0.61	20.0	28.9	25.6	0.91
1967	185,643	127,784	135,554		73,987	19,022	22,869	15,677	819	106		57.2	14.9	17.9	12.4	0.64	26.0	31.3	21.2	1.1
1968	159,048	114,158	96,662	80,678	72,357	24,377	24,920	13,719	1295	84.6	70.7	63.7	21.3	21.8	12.0	1.1	33.5	34.3	18.8	1.8
1969	231,838	173,801	151,298	129,595	79,375	16,796	31,556	14,679	1246	87.5	74.6	45.7	9.7	18.2	8.4	0.72	21.2	39.8	18.7	1.6

[1] "ANNUAL FISH PASSAGE REPORT, COLUMBIA RIVER PROJECTS, BONNEVILLE, THE DALLES, JOHN DAY, McNARY, SNAKE RIVER PROJECT, ICE HARBOR, 1968" NORTH PAC. DIV., CORPS OF ENGRS., U.S. ENGR. DISTRICTS, PORTLAND AND WALLA WALLA AND U.S. CORPS ENGRS. MONTHLY FISH PASSAGE REPORTS

[2] "THE 1969 STATUS REPORT OF THE COLUMBIA RIVER FISHERIES" FISH COMM. OREG. AND WASH. DEPT. FISH, JAN. 1970 (BONNEVILLE COUNT MINUS COMMERCIAL CATCH ABOVE BONNEVILLE AND ESCAPEMENT TO 5 HATCHERY STREAMS BETWEEN BONNEVILLE AND THE DALLES DAMS)

[3] GRANT CO. PUD WEEKLY FISH PASSAGE REPORTS - PRIEST RAPIDS DAM

[4] BASED ON A RATIO OF 2 FISH PER REDD

site. Mathews and Paulik (10) concluded that the presence of the Priest Rapids reservoir or construction activity in the Wanapum area may have forced fish over Rock Island Dam in 1960 to 1962. Davidson (9) noted a rise in the Rock Island count in 1963 to 1965, probably due to upstream displacement of fish from the destroyed spawning area between Wanapum and Rock Island Dams. A similar upstream displacement of The Dalles spawners to the Hanford area may also have occurred.

Another source of recent recruitment to the Hanford spawning population may have resulted from the upstream displacement of the main stem spawners that utilized the area upstream from the John Day Dam site prior to the establishment of the dam in 1968. Fall chinook tagging studies reported by Smith (5) showed that approximately 35 percent of the fish passing The Dalles Dam in 1965 were not accounted for at McNary Dam; and that this difference could not be assigned to tributary spawning. Fredd (11) and Junge (12) have also pointed out that significant intra-dam salmon losses occur that can not be accounted for by either main stem spawning or migration into tributary streams. Washington State Department of Fisheries aerial surveys of the John Day section of the Columbia from 1957 to 1961, as cited by Smith (5), show fall chinook counts ranging from 2 to 4294 fish and redd counts from 8 to 906. It was estimated that 10,000 fall chinook spawned in this part of the river in 1959. Fulton (13) estimated an average spawning population of 34,000 fish in the Columbia between McNary Dam and John Day Dam site in 1957-60, and ranked this section of the river second to the Snake River in production of fall chinook. This estimate of spawning appears to be high, and would result in very little or no loss of fish between the two dams, which, according to Fredd (11), is not the case. However, it seems reasonable to assume that part of this stock was displaced upstream to the Hanford area during the construction and completion of John Day Dam, and has contributed to the increased Hanford spawning population since 1966. As pointed out by Fulton (13), the stretch of river between the head of McNary Pool and Priest Rapids Dam is the primary main stem spawning area remaining. Some main stem spawning does occur above Priest Rapids. Meekin (14) observed a total of 177 redds in the Columbia in 1969 between Priest Rapids and Rock Island Dams. However, some of these may have been from summer chinook spawning. The release of fall chinook fry from the Washington State Department of Fisheries spawning channel at Priest Rapids (km 639) and their rearing station at Ringold (km 565) may have contributed fish to the Hanford spawning stock. Priest Rapids fry releases have varied from about 350,000 (1964) to over 7,000,000 (1967) during the period 1963-68. Return of the adults to the spawning channel outlet stream has been negligible, however. Ringold fry releases have ranged from 98,000 (1961) to 3,000,000 (1968) with adult returns of 7 to 1290. The contribution of these fry releases to the Hanford spawning stock is difficult to evaluate, but adult returns to the rearing station do not indicate runs of a size sufficient to explain the recent increases in the Hanford population.

RELATIONSHIP OF REDD COUNTS TO ESCAPEMENT

The fall chinook redd counts near Hanford can be compared with the escapement above Bonneville Dam and the fall count at McNary Dam in Figure 5 and Table 3. The long-term trends, as computed by the method of least squares, are ascending at all three locations, but the increase with time

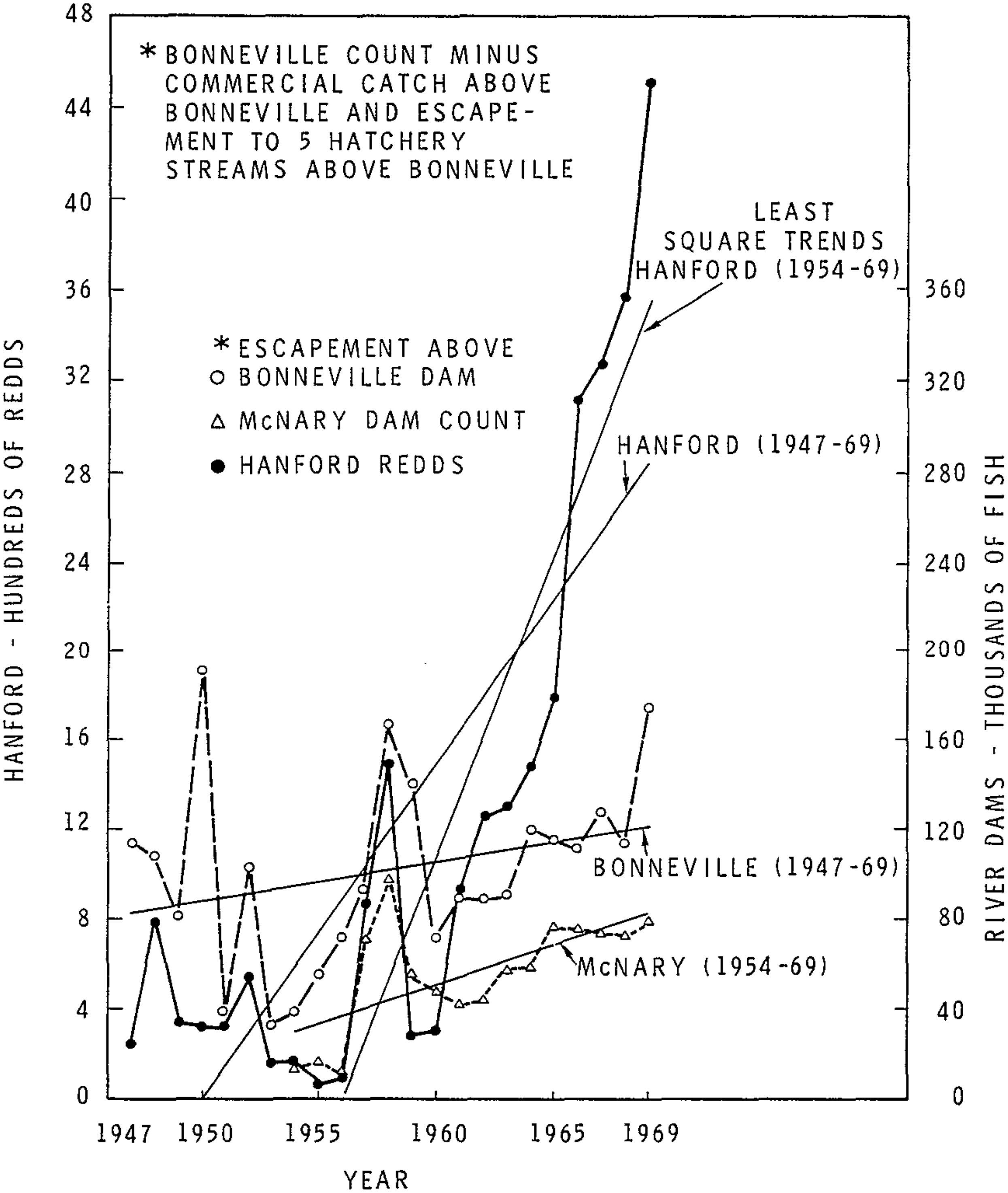

FIGURE 5. FALL CHINOOK ESCAPEMENT TO THE COLUMBIA RIVER AND SPAWNING NEAR HANFORD 1947-69

is much greater for the Hanford spawners. There has been a significant and steady increase in numbers of Hanford redds every year since 1960. Although there has been a general increase during this same time at both Bonneville and McNary it has not been as great as that of the Hanford population.

The sharp rise in the Hanford stock in recent years also can be shown by comparing the observed redd counts with the brood years contributing to the spawning return (Figure 6). The age composition given by Junge and Oakley (15), obtained from Oregon Fish Commission and State of Washington Department of Fisheries age analysis of the commercial catch in the Columbia gill-net fishery in 1957-64, was used to estimate the contribution of the several brood years to the number of spawners returning in a given year. With the exception of the 1960 return, all years since then have equaled or exceeded a 1 to 1 ratio of returning spawners to parent fish. The only years prior to 1960 that had a greater than 1 to 1 ratio were 1957, 1958, and 1959, the period immediately following the completion of The Dalles Dam, and the time of construction of Priest Rapids Dam. Since 1960 the average return to parent ratio is slightly greater than 2. (regression coefficient = 1.893 for 1952-69)

A similar comparison of fall chinook return to escapement, as derived from adult counts at McNary Dam (Figure 7), shows a greater than 1 to 1 ratio of return to brood year for all years except 1961 and 1962, but on only one year, 1959, did the ratio exceed two. (regression coefficient = 0.959 for 1952-69) Factors affecting the abundance of the Hanford spawners are clearly not applicable to the same degree on the run over McNary.

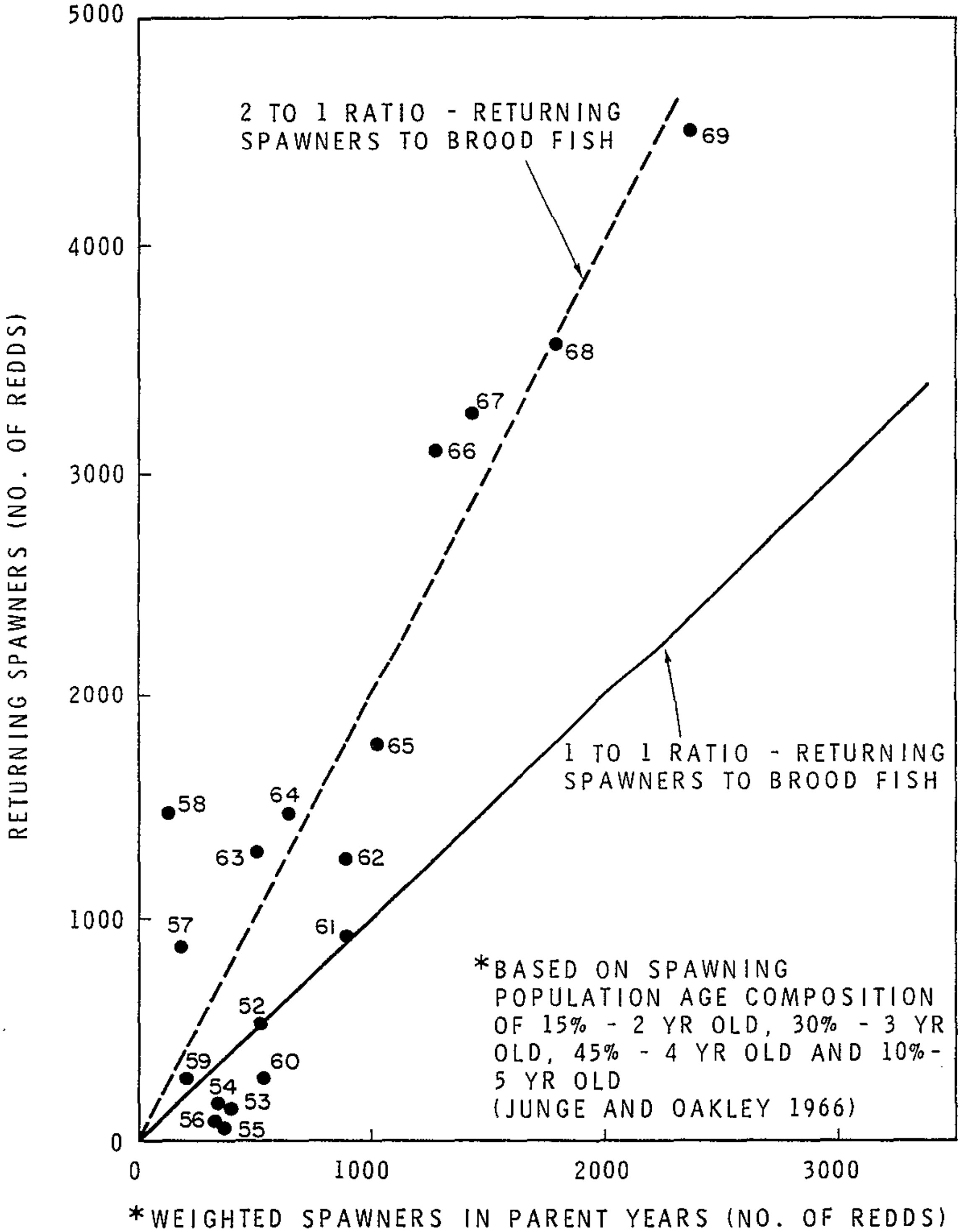

FIGURE 6. RELATIONSHIP OF SPAWNING STOCK TO BROOD YEARS

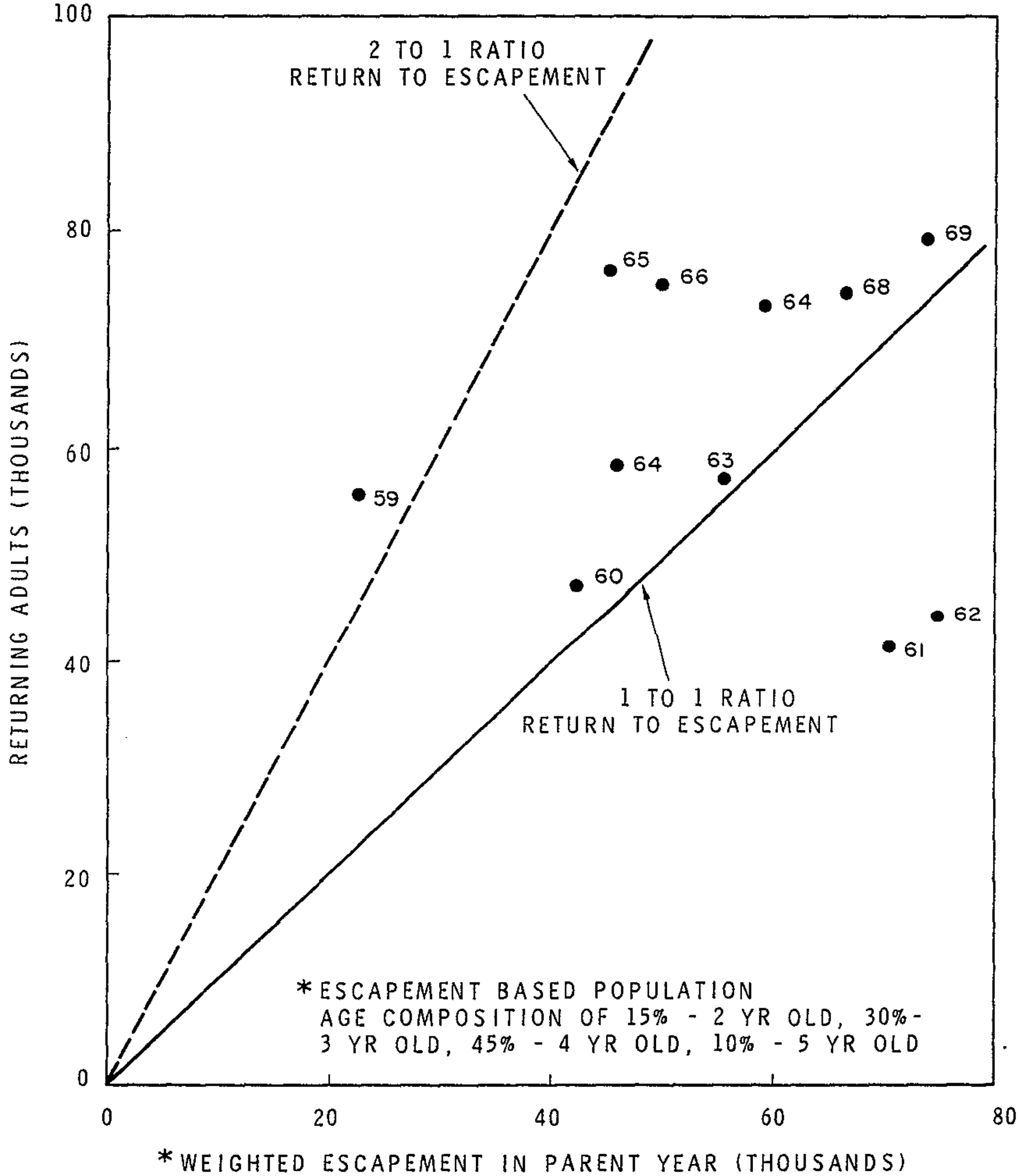

FIGURE 7. McNARY DAM - RETURN TO ESCAPEMENT

The relationship of the Hanford population to escapement above Bonneville is given in Table 3 (ratio G/B). In 1955 and 1956 the number of Hanford spawners was less than one percent of the Bonneville escapement. Since 1960, there has been a sharp increase in the proportion of Hanford spawners to Bonneville escapement, approaching 20 percent during the last four years. This coincides with the period of construction and first two years of operation of John Day Dam.

Starting with the escapement of fall chinook above Bonneville Dam there was a decline in the number of fish passing each succeeding dam (Figure 8). The magnitude and possible reasons for these differences have been analyzed by Fredd (11). During the period from 1962 to 1969, the average numbers of fall chinook passing Ice Harbor-Priest Rapids Dams and the estimated spawning near Hanford were about the same, about 15 percent of the Bonneville escapement. The average percentage at Ice Harbor is inflated by what appears to be an erroneously high count in 1962 (Table 3, columns 14 and 18). The "unaccounted for" part of the run in the section of the Columbia and Snake Rivers between McNary and Ice Harbor - Priest Rapids Dams is given in Figure 9. It is evident that the "unaccounted for" fish are more closely associated with the segment of the run passing up the Snake River than they are with those continuing up the Columbia. The yearly changes in the Ice Harbor counts are inversely related to the "unaccounted for" segment. The portion of the run continuing up the Columbia above McNary has shown much less variation than the Snake River run, and has ranged from 50 to 60 percent of the McNary count. Numbers of fish spawning near Hanford and those ascending Priest Rapids Dam are also inversely

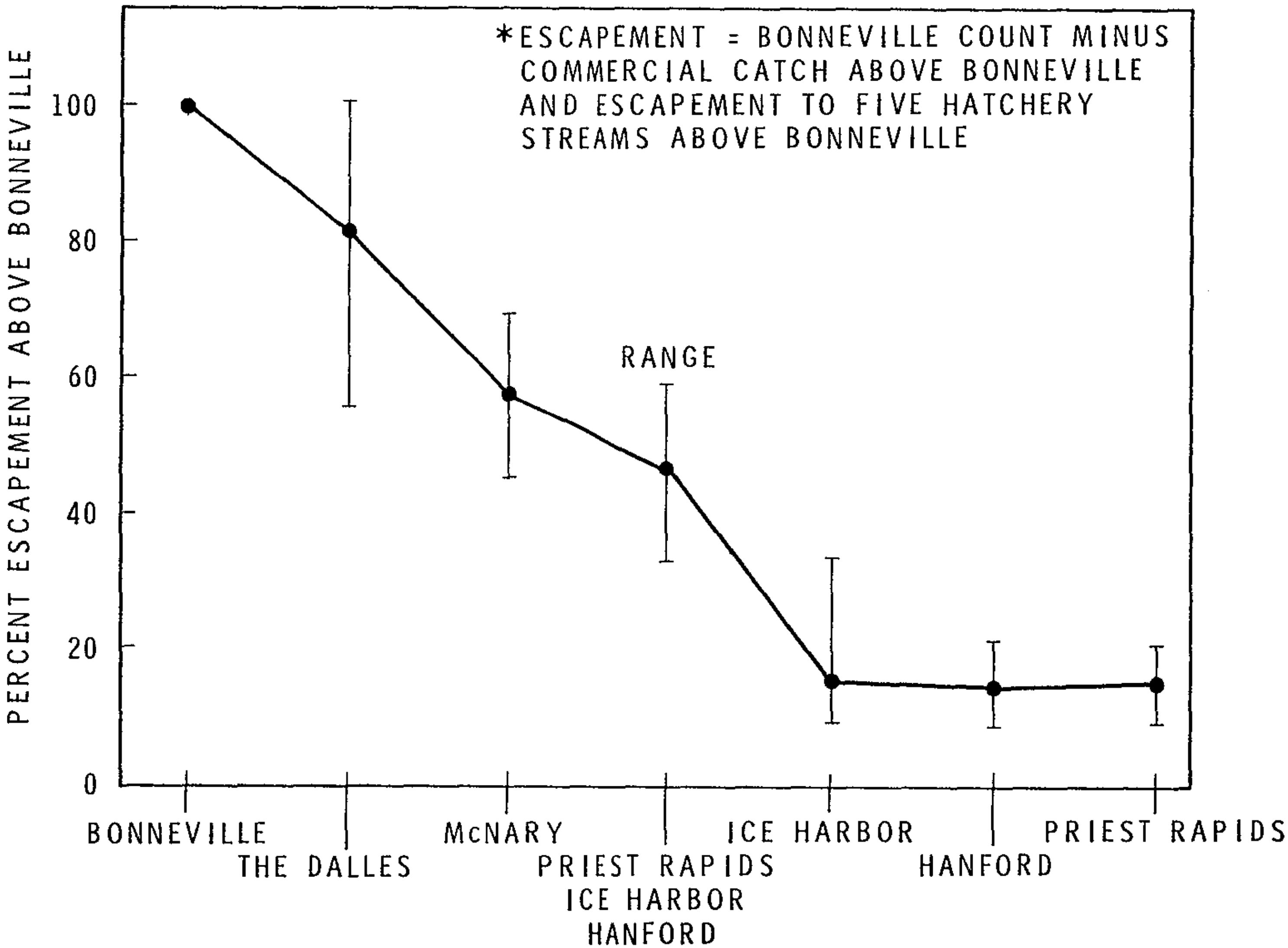

FIGURE 8. RELATIONSHIP OF FALL CHINOOK SALMON* ESCAPEMENT ABOVE BONNEVILLE DAM TO PASSAGE OVER UPSTREAM DAMS AND SPAWNING NEAR HANFORD 1962-69

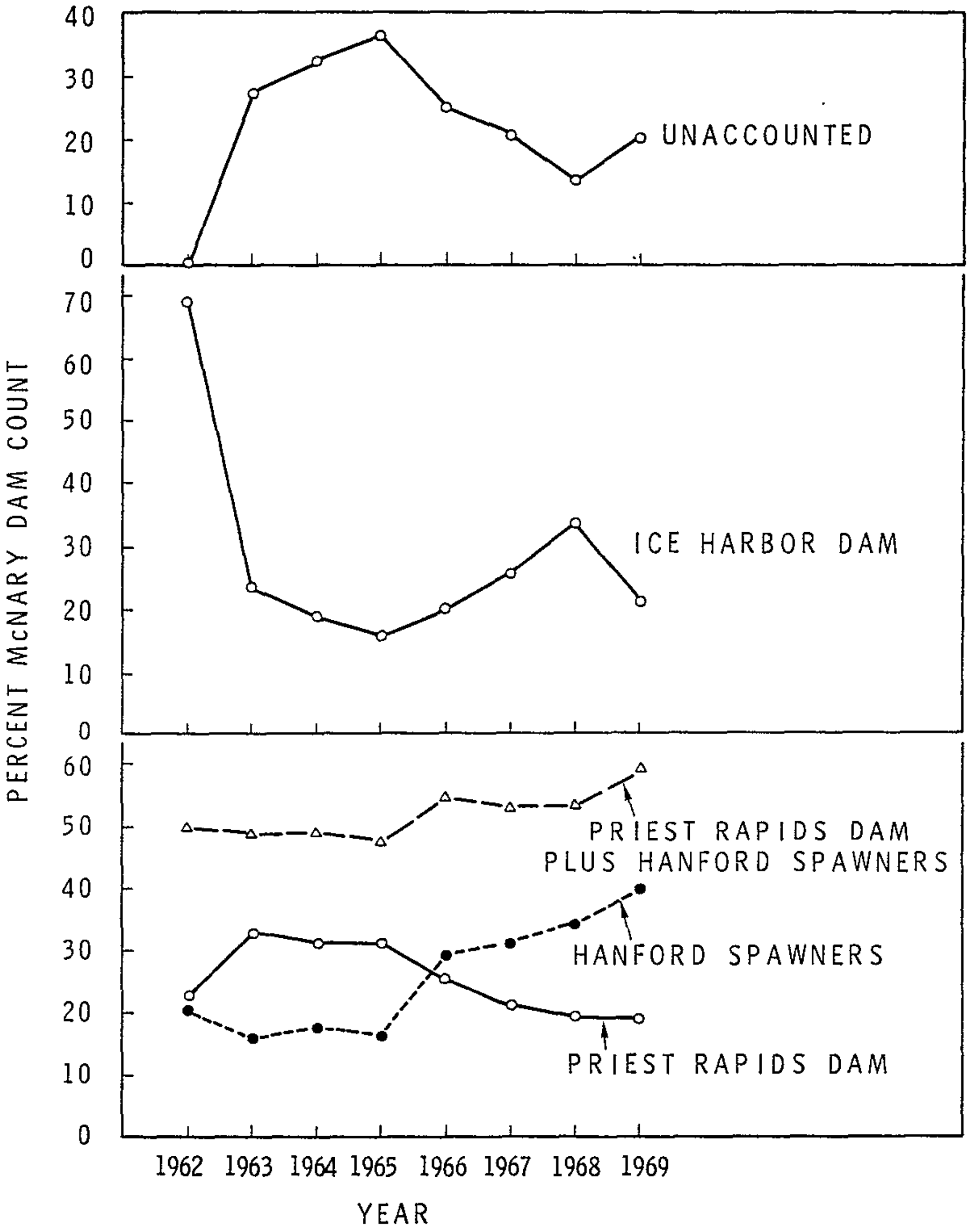

FIGURE 9. RELATIONSHIP OF FALL CHINOOK PASSING McNARY DAM TO THE RUN UPSTREAM

related. Whether this relationship is real, or merely reflects the apparent recent upstream displacement of down river populations to the Hanford area is unknown.

Part of the "unaccounted for" fish spawn in the lower Yakima River. The lower 30 km of the Yakima were surveyed at the same time as the Hanford area in 1961 to 1969, and the results are given in Table 4. The return of irrigation water to the lower Yakima River during the fall made the water too turbid for good visibility of the river bottom, thus limiting the effectiveness of aerial surveys. In 1969 an estimated 2500 fall chinook spawned in the lower Yakima River, the maximum for the period of observation. According to Meekin (14) there is no fall chinook spawning upstream from Prosser (river km 40) and none in the Walla Walla River, the only other tributary to the Columbia in this region. Lower Yakima River spawning may account for up to 3 percent of the fall passage over McNary Dam, however.

An average of 25 percent (range 13 to 37 percent) of the fall chinook in the Columbia between McNary and Ice Harbor-Priest Rapids were unaccounted for (uncorrected for Yakima River spawning) during 1963-69. For spring chinook (1962-69) the average was 27 percent (range 15 to 40 percent), and summer chinook 15 percent (range 6.5 to 24 percent). The "loss" of fall chinook in this section of the Columbia is not much different than that of the spring and summer runs, particularly if the fall spawning in the lower Yakima is considered. Fredd (11) reported fall chinook "losses" of 40 to 51 percent for this section of the river in 1963 to 1965, but he did not account for the fish spawning in the Hanford reach.

Table 4

FALL CHINOOK SALMON SPAWNING IN THE

YAKIMA RIVER (LOWER 30 km) 1959-69

Year	Number of redds	*Number of fish (redds x3)
1959	0	0
60	-	-
61	29	87
62	5	15
63	108	324
64	40	120
65	66	198
66	135	405
67	177	531
68	62	186
69	829	2487

* Fish to redd ratio of 3, instead of 7, used because of shallow depth of the Yakima River.

Temperature, Flow, Elevation

The effects of the variables, temperature, flow, and fluctuating river elevation on local salmon spawning are difficult to evaluate directly because of other environmental changes that have occurred during the period of study. Average weekly temperatures along with the maximum and minimum daily temperatures for the river upstream from the reactors are shown in Figure 10. These data were derived from temperature records reported by Foster and Olson (16) for 1947 to 1958 and from measurements obtained from the Atomic Energy Commission-Geological Survey gauging station below Priest Rapids Dam for 1960 to 1969. The maximum values represent the highest average daily temperatures observed for the 1947-69 period and are not necessarily typical of any single year. During the normal spawning period, beginning in some years as early as the first week in October, mean weekly temperatures were about 15.5 °C and the maximum mean daily temperature slightly less than 18° C. In Figure 11, the upstream temperatures are compared with those at Richland for 1965-69. The weekly means at Richland are about 1° C higher than those upstream from the reactors during the start of spawning. Maximum daily temperatures of nearly 20° C have been measured in September. A difference of approximately 3.5° C has been reported for a single day in September 1966 by Davis and Snyder (17). The temperature differences between Priest Rapids and Richland are not entirely due to the heat introduced into the river by the reactors. In July and August of 1966 when all reactors were shut down due to a labor dispute, Richland temperatures were about 1.7° C greater than those at Priest Rapids and were the result of natural heating of the water, probably from insolation.

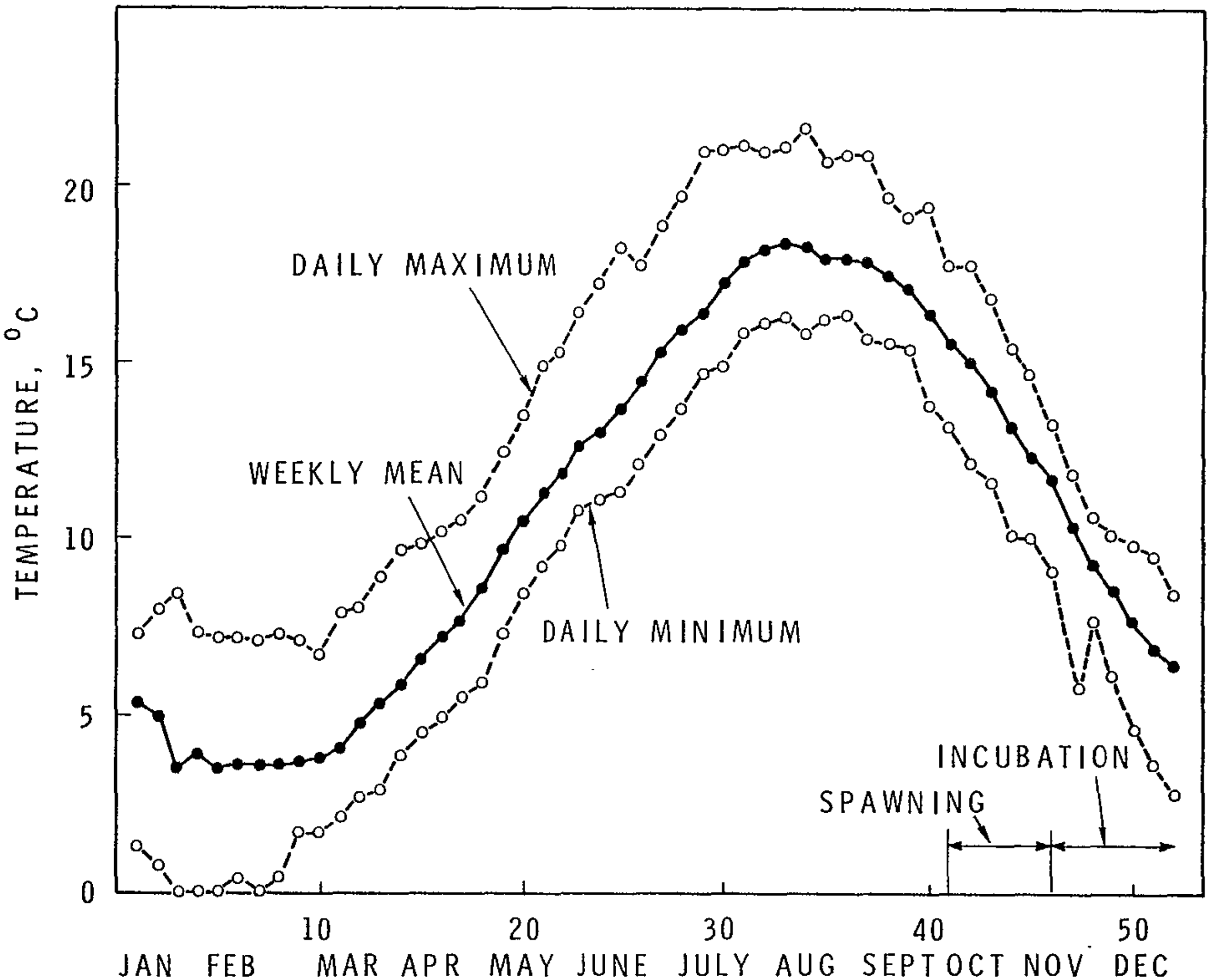

FIGURE 10. COLUMBIA RIVER TEMPERATURES UPSTREAM FROM THE REACTORS 1947-69 (1959 RECORDS NOT AVAILABLE FOR JAN.-AUG.)

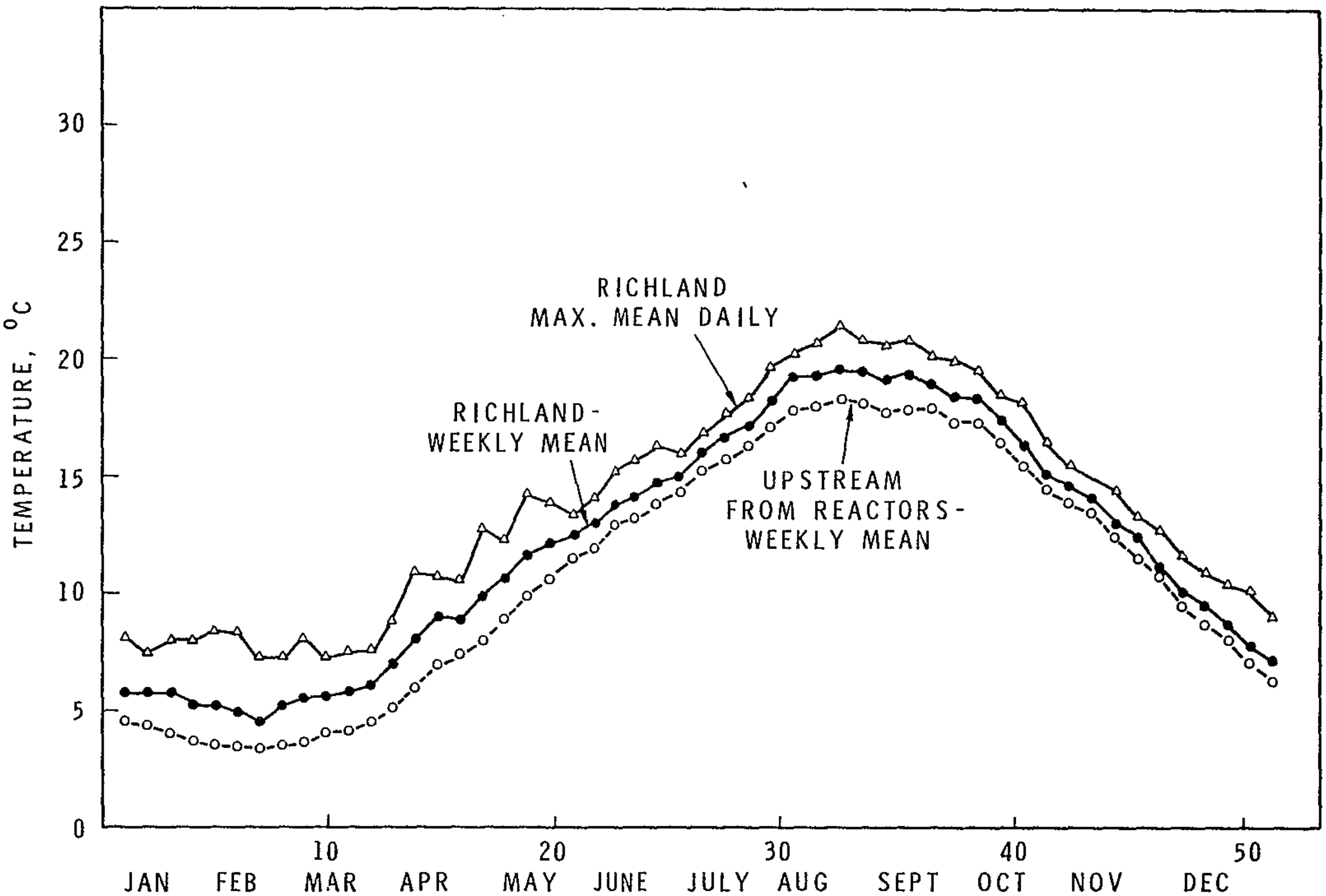

FIGURE 11. COLUMBIA RIVER TEMPERATURES - 1965-69

The effect of upstream dams on river temperatures has been reviewed by Jaske and Goebel (18). Low-head reservoirs have not produced any significant change in main stem Columbia River temperatures, but the creation of Lake Roosevelt back of Grand Coulee Dam has delayed the time of maximum temperature about 30 days and has reduced the annual variance. A further shift in the season of temperature maxima after the completion of the Canadian Treaty Dams is also expected. This may be of ecological significance to main stem spawning populations.

The mean weekly water temperatures (upstream from the reactor outfalls) at the start, peak and end of spawning are shown in Table 5. The average temperature at start of spawning was 15.4° C, with a maximum of nearly 19° C observed in 1958. The maximum observed temperature is probably in error due to the upstream drift of heated effluents to the area where the temperatures were measured in 1958. By the peak of spawning, temperatures averaged 13.4° C with a maximum of 15.1° C, and by the end of spawning average temperature decreased to 10.4° C with the maximum of 11.4° C. Peak of spawning temperatures were higher than the 12.8° C recommended upper limit suggested by the Fish and Wildlife Service (19), but were below the 16° C preferred upper limit for Pacific salmon reported by Novotny and quoted by Davis and Snyder (17). Temperature tests conducted by Coutant (20) indicate that prolonged exposure to temperatures above 21° C would be directly lethal to chinook jack. In recent times fall temperatures of the main stem Columbia nearly always have been greater than 12.8° C during the spawning season, and were probably so before the coming of dams, irrigation projects, industry and nuclear reactors. Fall chinook passing through the lower Snake River are commonly exposed to temperatures

TABLE 5. PHYSICAL CONDITIONS OF THE COLUMBIA RIVER UPSTREAM FROM THE REACTORS DURING SALMON SPAWNING

	BEGINNING[1]						PEAK	END
YEAR	WEEK	FLOW $X10^{-3}$ m^3/sec	(FT^3/sec)	DAILY CHANGE IN ELEVATION m	(FT)	TEMP. °C	TEMP. °C (OCT.29-NOV.4)	TEMP. °C (NOV. 19-25)
1950	*OCT. 15-21	1.94	(68.4)			15.0	13.1	9.8
1951	OCT. 15-21	2.27	(80.2)			14.5	12.1	9.6
1952	OCT. 15-21	1.60	(56.4)			15.8	14.3	11.3
1953	OCT. 15-21	2.16	(76.4)			15.4	13.3	10.5
1954	*OCT. 15-21	2.13	(75.2)			13.4	12.3	11.0
1955	OCT. 8-14	1.91	(67.5)			14.7	12.4	8.1
1956	*OCT. 15-21	1.85	(65.2)			14.8	13.4	9.9
1957	*OCT. 1-7	1.86	(65.5)			16.2	13.7	10.5
1958	*OCT. 1-7	1.85	(65.3)			18.9	15.1	10.6
1959	OCT. 8-14	2.93	(103.6)			---	---	---
1960	SEPT. 24-30	2.36	(83.3)	0.61	(2.0)	16.8	13.4	10.6
1961	-----------	---	---	---	---	---	12.8	9.3
1962	*OCT. 8-14	1.77	(62.6)	1.34	(4.4)	14.3	14.3	10.7
1963	OCT. 8-14	1.83	(64.5)	1.43	(4.7)	17.1	13.6	11.4
1964	OCT. 15-21	2.61	(92.2)	1.95	(6.4)	14.7	13.1	10.0
1965	OCT. 15-21	1.82	(64.3)	2.10	(6.9)	14.7	13.7	11.4
1966	OCT. 8-14	2.12	(75.0)	2.59	(8.5)	15.1	13.3	10.8
1967	*OCT. 15-21	2.15	(75.9)	2.33	(7.7)	15.4	13.2	10.8
1968	OCT. 1-7	2.44	(86.2)	1.95	(6.4)	16.0	12.7	10.1
1969	OCT. 8-14	2.44	(86.3)	2.26	(7.4)	15.1	13.9	10.3
MEAN		2.11	(74.4)	1.84	(6.0)	15.4	13.4	10.4

[1]BEGINNING OF REDD EXCAVATION

*ESTIMATED

greater than 20° C.

In laboratory tests conducted at Hanford, Olson and Foster (21) found no excessive mortality when fall chinook egg incubation began at 16° C; and no significant loss when incubation temperatures were 2.2° C greater than the ambient Columbia River temperatures downstream from the reactors. Combs (22) lists 14.2 to 15.5° C as the upper threshold limit for incubation of chinook eggs. Hanford temperatures at the start of spawning were near the upper limit of this threshold, but by the end of spawning and during the most of the embryonic development and early life stages temperatures were well below the upper limit.

During November 1954 through May 1955, temperatures were measured in the river bottom gravel of a simulated salmon redd in a zone of incompletely mixed effluent near river km 591. Temperatures were taken at 1.5 decimeters above the river bottom and at 1.5, 3.8, 5.3, and 7.6 dm below the bottom surface. The bottom gravel in the area where the temperatures were taken was typical of salmon spawning areas, although it was not used for spawning. Easy access from shore and the proximity to an effluent outfall were the controlling factors in site selection.

Temperature profiles of the river bottom are shown in Figure 12. Only infrequently did intragravel temperatures exceed that of the free-flowing river, and this was usually at depths greater than that of normal egg deposition. Burner (23) has reported average and maximum redd depths of 2.6 dm and 4.5 dm respectively for fall chinook in Columbia River tributaries. During the period of egg and fry residence in the gravel (November-February), the difference between the river bottom temperature and the water above was

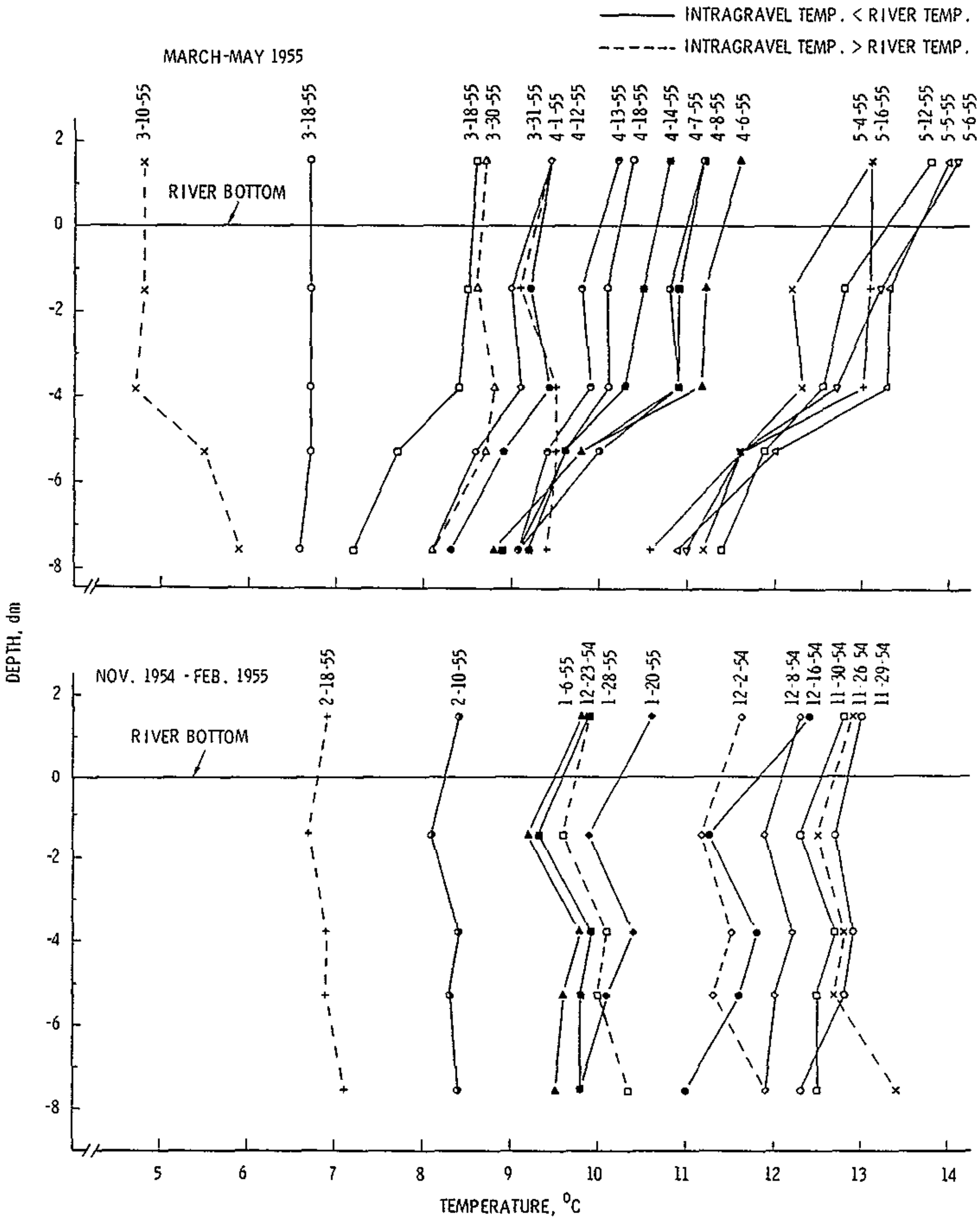

FIGURE 12. RIVER BOTTOM TEMPERATURE PROFILES IN ZONE OF INCOMPLETELY MIXED REACTOR EFFLUENT 1954-55

usually less than 1 °C. The gravel temperature at 1.5 dm was consistently less than that at 3.8 dm or 5.3 dm depths, or that near the river bottom in November through February. Differences between the river and the gravel were as great as 3°C from March through May. For the November-May period, river temperatures taken just upstream from the effluent outfall ranged from 0.6 to 4 °C less than that at the simulated redd.

Continuous temperature measurements were made at the same location in the fall of 1955 at 1.5 dm above the bottom and 3.8 dm in the gravel. Temperatures at these points were essentially the same, although changes in temperature within the gravel lagged 30 to 60 minutes behind that of the river. It should be remembered that these measurements were not necessarily typical of any salmon spawning areas, and were markedly influenced by the fluctuations in operation of the reactor immediately upstream. They do suggest, however, that in areas receiving thermal additions, temperatures in the stream bottom are similar to or less than that of the river proper.

The diurnal changes in river elevation resulting from variable water release at Priest Rapids Dam has caused some redds to be left out of water during low flows. Daily changes in river elevation during the spawning season were usually a meter or more (Table 5), and maximum daily flow was often more than twice the minimum. Greatest observed numbers of redds exposed to the air were 34 and 17, in 1960 and 1964 respectively. Others were noted in 1961 and 1967. Exposed redds could have gone unnoticed on many surveys that were conducted during times of greater than daily minimum river elevation. The significance of this redd exposure as a cause of egg mortality has not been determined. Meekin (6) reported no significant loss of developing embryos in exposed chinook redds during low flows in spawning areas downstream from Chief Joseph Dam in 1966-67. There was sufficient ground water percolation at the depth of egg deposition to sustain life. Some of the redds had been abandoned before any spawning had taken place. Although the diurnal fluctuation in river elevation may have little direct effect on the survival of the spawn, it does tend to reduce the available spawning area.

Variation in the estimated number of salmon redds in the Columbia River near Hanford was related by Gilbert (24) to environmental variables such as river temperature, flow and elevation at spawning, and to number of operating reactors and dams downstream from Hanford. The basic approach used was a step-wise regression which uses both simple correlation and step-wise multiple regression techniques. A computer program was used in all analyses. Gilbert emphasized that cause and effect relationships can not be established by these techniques, but some knowledge concerning the correlation of the variables may be obtained.

Hanford fall chinook redd estimates were positively correlated with escapement above Bonneville and McNary Dams, and with number of dams downstream from Hanford. Redd counts were negatively correlated with fall chinook passage over Priest Rapids Dam and with number of operating reactors (1962-69). No correlation, however, was found between redd estimates and number of operating reactors for the period 1947-60. There was a slight negative correlation between redd counts and fall chinook passage over Priest Rapids Dam. The above relationships may or may not be real. Their value lies in pointing out areas where more intensive future studies should be made. High river flows tended to be associated with low redd estimates. This may be only a measure of the effect of water depth on the ability to see the redds and not a true estimate of the relationship of high flows on actual numbers of redds present.

Gilbert's analyses were supplemented by Paulik (25), who used a different method of selecting independent variables in the regression equations, and different functional forms were used to represent the effect of certain independent factors in the regression equations. Paulik compared the rate of change with time in the several spawning sub-areas within the Hanford reach of the river. The rate of increase of the upstream area (km 633) was similar to that at the next major downstream area (km 600-605). He concludes that "these data provide no evidence of a reactor effect; if such an effect does exist, it is masked by other events occurring during the period of observation". He further states "that dam construction during the past 23 years was probably the critical factor controlling the numbers of fall chinook spawning in the Hanford area".

Future studies on salmon population dynamics should include more of the variables important to the survival of the local stock. Some estimate of the variability in redd counts will also be needed. Other statistical approaches should be explored to find one better than the step-wise regression. Some better quantification of reactor heat discharge and the effect of dam construction, other than number of dams and reactors is needed to measure the effects of these variables on the Columbia River salmon.

CONCLUSIONS

1. For the period 1947-69 there was no apparent relationship between numbers of fall chinook salmon spawning in the Hanford reach of the Columbia River and river temperature, flow or elevation during the spawning season.
2. Closure of reactors immediately upstream from major spawning areas did not alter the general distribution of the spawning fish.
3. The marked increases in numbers of fall chinook using the Hanford section of the Columbia for spawning since 1960 were probably the result of a partial barrier to upstream movement created by Priest Rapids Dam, and the upstream translocation of main stem spawning populations whose spawning grounds had been eliminated by dams downstream from Hanford.
4. The increased utilization of the spawning grounds immediately downstream from Priest Rapids and upstream from reactor effluent outfalls has not been at the expense of spawning within the area of the river receiving effluents.
5. Since 1962, the "unaccounted for" portion of the fall chinook between McNary and Ice Harbor - Priest Rapids Dams has been comparable to that of the spring and summer runs. This "loss" of fish was much more closely related to the portion of the fall run entering the Snake River than to the segment of the run continuing up the Columbia.
6. The success of the Hanford population during the 1947-69 period was much better than the overall fall run in the Columbia River, as measured by the adult escapement above Bonneville Dam, or since 1954, to the passage over McNary Dam. There was no evidence, however, that this was due to any beneficial effect

of the Hanford reactors.

7. The assessment of any subtle biological effects of the reactors on the local salmon population was not possible in a study of this kind. Other changes in the ecology of the river, such as those produced by dams, appeared to be of greater influence on the numbers of locally spawning salmon than the reactor operation.

8. The Hanford section is the principal remaining main stem spawning area in the Columbia and is of major importance as a breeding ground for fall chinook. Since 1962 an estimated average of 15 percent of the fall escapement above Bonneville and 33 percent of the run over McNary have spawned here. It is therefore important that study of this population be continued and expanded in the future to determine conditions necessary for their survival.

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